



Modification of Upsilon production in nuclear collisions measured with sPHENIX



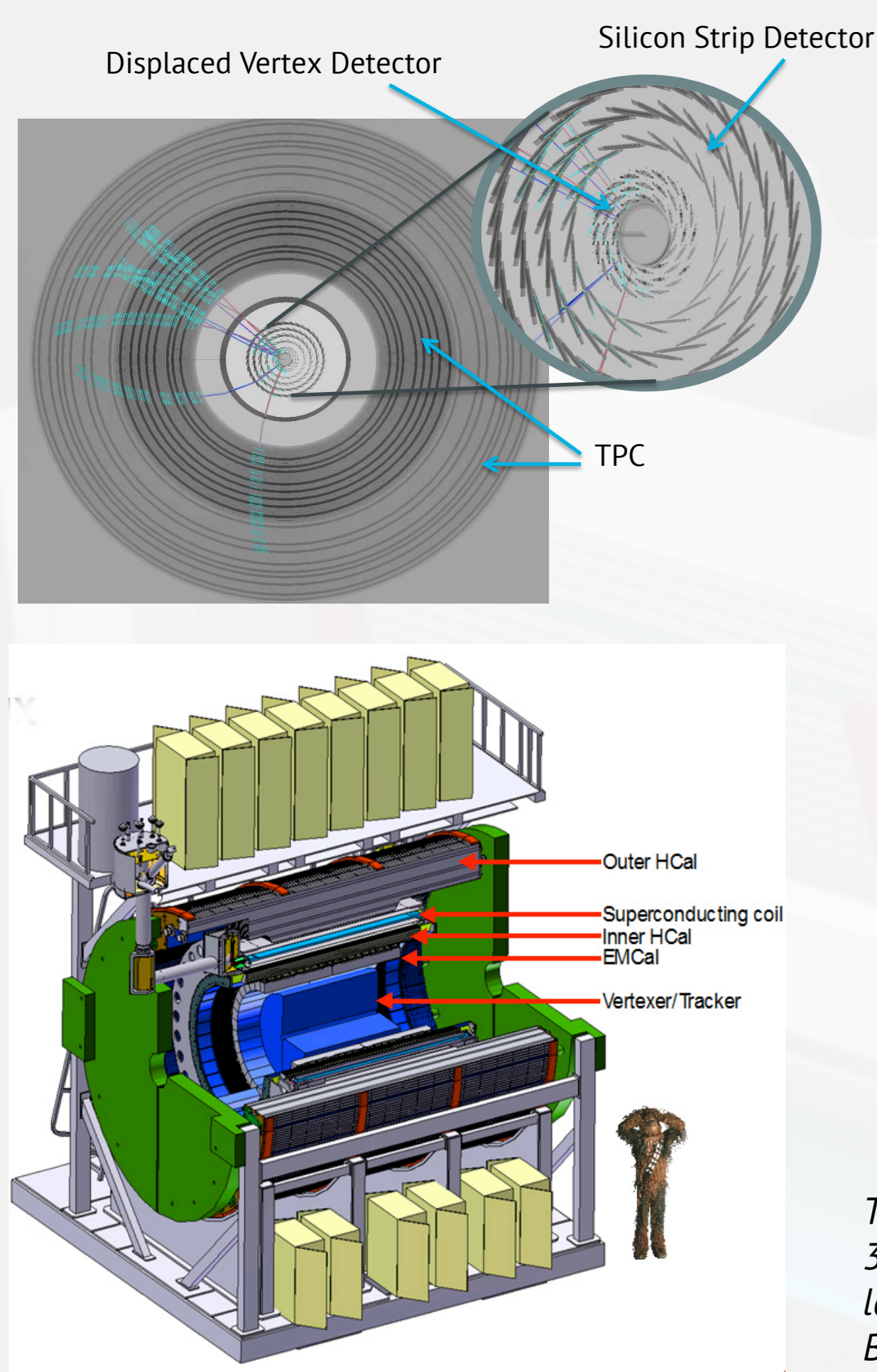
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Abstract

Upsilon provide an excellent probe for studying the screening length in the Quark Gluon Plasma through simultaneous observation of the $Y(1S)$, $Y(2S)$ and $Y(3S)$, using pp, pA and AA collisions. Unlike the charmonium states, the Y yield in AA collisions due to coalescence of bottom quarks produced in unrelated hard processes is expected to be small at both RHIC and LHC energies. Comparison of the Y modifications measured at RHIC and LHC therefore provides a relatively direct comparison of the effect of the energy density on three states of different radius and binding energy, at two different initial temperatures of the plasma. The sPHENIX experiment proposed at RHIC will be able to reconstruct Y states with a mass resolution better than 100 MeV, providing a clear separation of the three $Y(nS)$ states. In combination with the large acceptance of sPHENIX, and the high luminosity at RHIC this will provide a high quality measurement of the modification for all three states. The results of simulations showing the performance of sPHENIX as an Upsilon detector will be described, and the expected quality of the measurements will be discussed.

sPHENIX Motivation

The sPHENIX detector was proposed to provide RHIC with a state of the art jet and Upsilon detector [1]. Design and construction is currently underway, and sPHENIX is expected to begin taking data in January 2021. The three main legs of the program are light quark jets, heavy quark jets and Upsilon. sPHENIX will operate at collision energies of 200 GeV/nucleon, while the LHC will operate at energies of 5.5 TeV/nucleon, thus delivering two good quality jet and Upsilon measurements at two widely different initial temperatures. sPHENIX will be capable of probing the QGP over a wide range of length scales, and will provide at RHIC the mass resolution necessary to separate all three Y states.



sPHENIX Tracker

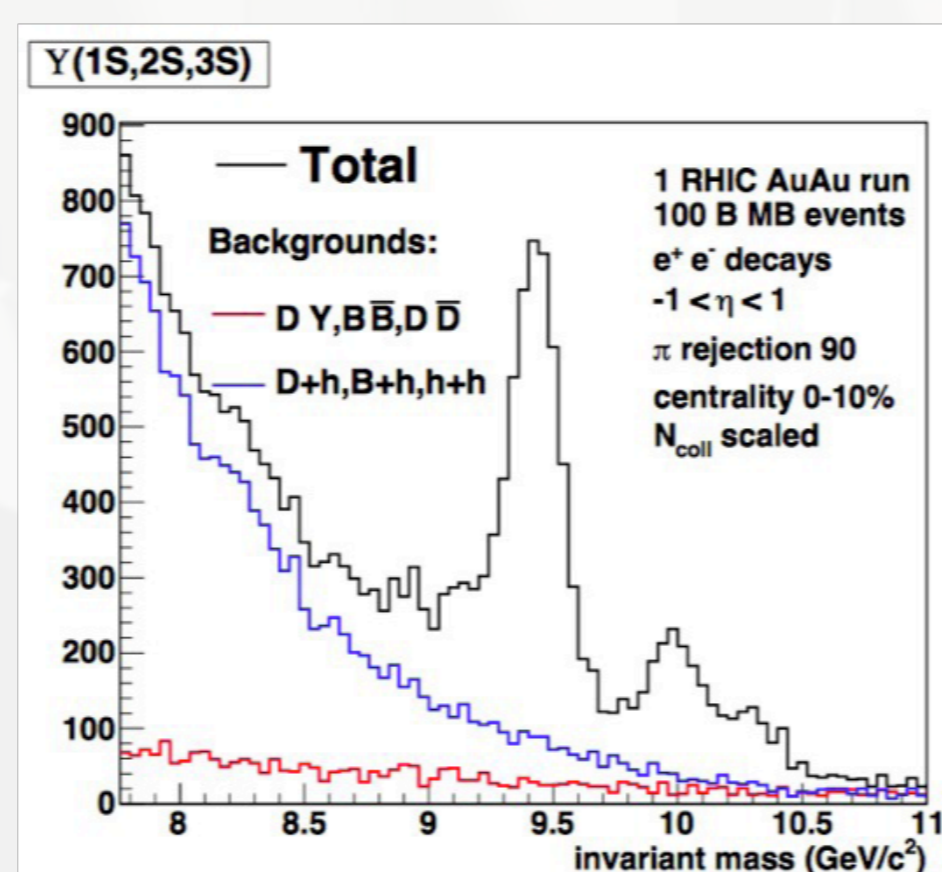
The sPHENIX tracking system consists of three Monolithic Active Pixel Sensor (MAPS) layers plus four Intermediate layers of silicon strips and a Time Projection Chamber (TPC). The tracking system is a critical part of the heavy quark jets program as well as being necessary to study the charged tracks substructure in jets. Jets are detected by their energy deposit in the Electromagnetic Calorimeter (EMCal) and the Hadronic Calorimeter (HCal), both hermetic detectors with full 360 degree azimuthal coverage, while the MAPS layers, a precision vertex detector, identify the heavy quark jets (charm, bottom). The most critical component of the sPHENIX detector for the Upsilon program is the tracking system. For Upsilon spectroscopy, an invariant mass resolution of about 1% is needed to resolve the $Y(1s)$, $Y(2s)$ and $Y(3s)$ states.

Top: Computer simulated image of tracking system, which includes 3 inner (pixel) MAPS layers, 4 silicon (strip) Intermediate Tracking layers and the TPC. Inset: MAPS and Intermediate tracking layers. Bottom: Engineering image of the full sPHENIX detector, including the EmCal, Hcal, BaBar solenoid and the tracking system.

Particle Identification/Background Estimation

For the beauty quarkonia physics program, the electromagnetic calorimeter (EMCal) in conjunction with the hadronic calorimeter (Hcal) and the tracker identify the electron tracks arising from Upsilon decay by comparing momentum with measured energy. Between the momentum ranges of 4-8 GeV, electron ID efficiency is 95% for p-p events.

The pion tracks, which constitute the largest background noise in the invariant mass spectrum, are rejected by the direct comparison of energy deposition and track momentum in the EMCal and the HCal. In Au+Au collisions, pion rejection is 100:1 with 90% single electron efficiency using EMCal and HCal energy, shower shape and track momentum. The background consisting of correlated charm and bottom along with the Drell-Yan is shown in red, while the combinatoric background resulting from misidentified hadrons and electrons from heavy quark jets is shown in blue.



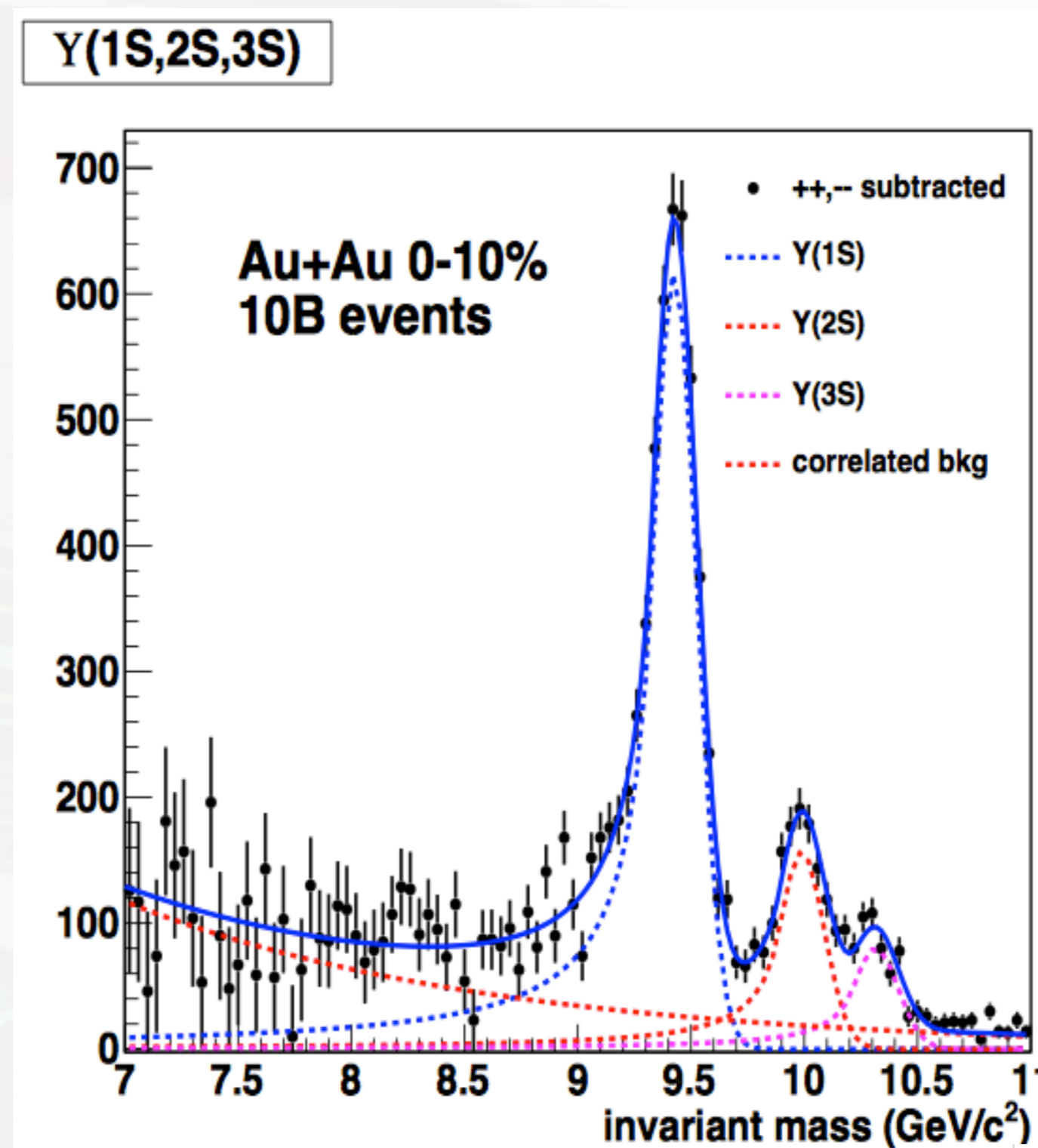
Plot of simulated Upsilon mass resolution for $Y(1s)$, $Y(2s)$ and $Y(3s)$ states from 10 billion Au+Au events with 0-10% centrality. Background includes correlated charm, correlated bottom, Drell-Yan and pions incorrectly identified.

Simulations

GEANT4 was used for simulations of tracking performance. Single Upsilon simulations are combined with a fast simulation of background based on a GEANT4 simulation of the calorimeter response to pions and electrons in 200 GeV Au+Au collisions.

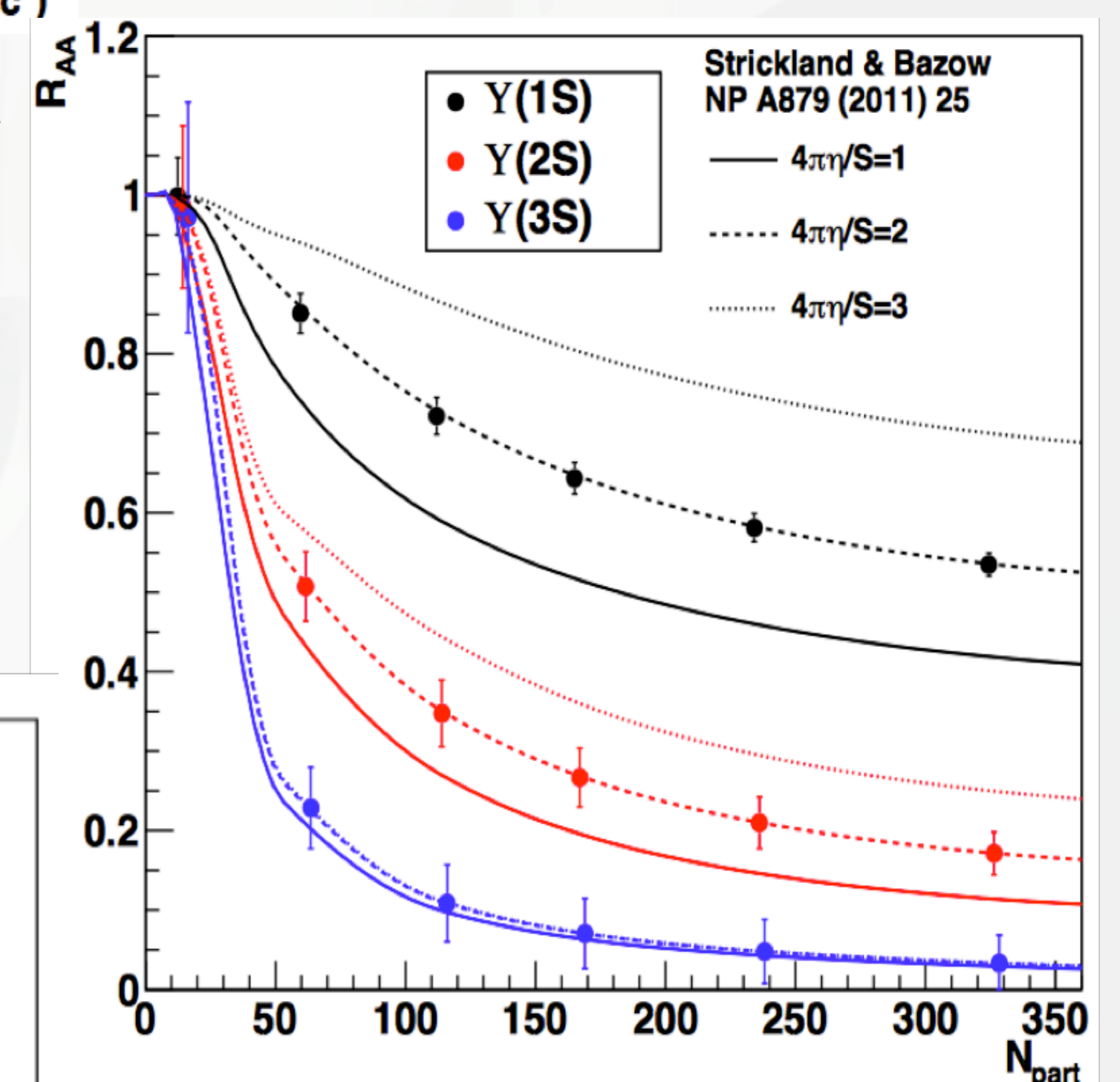
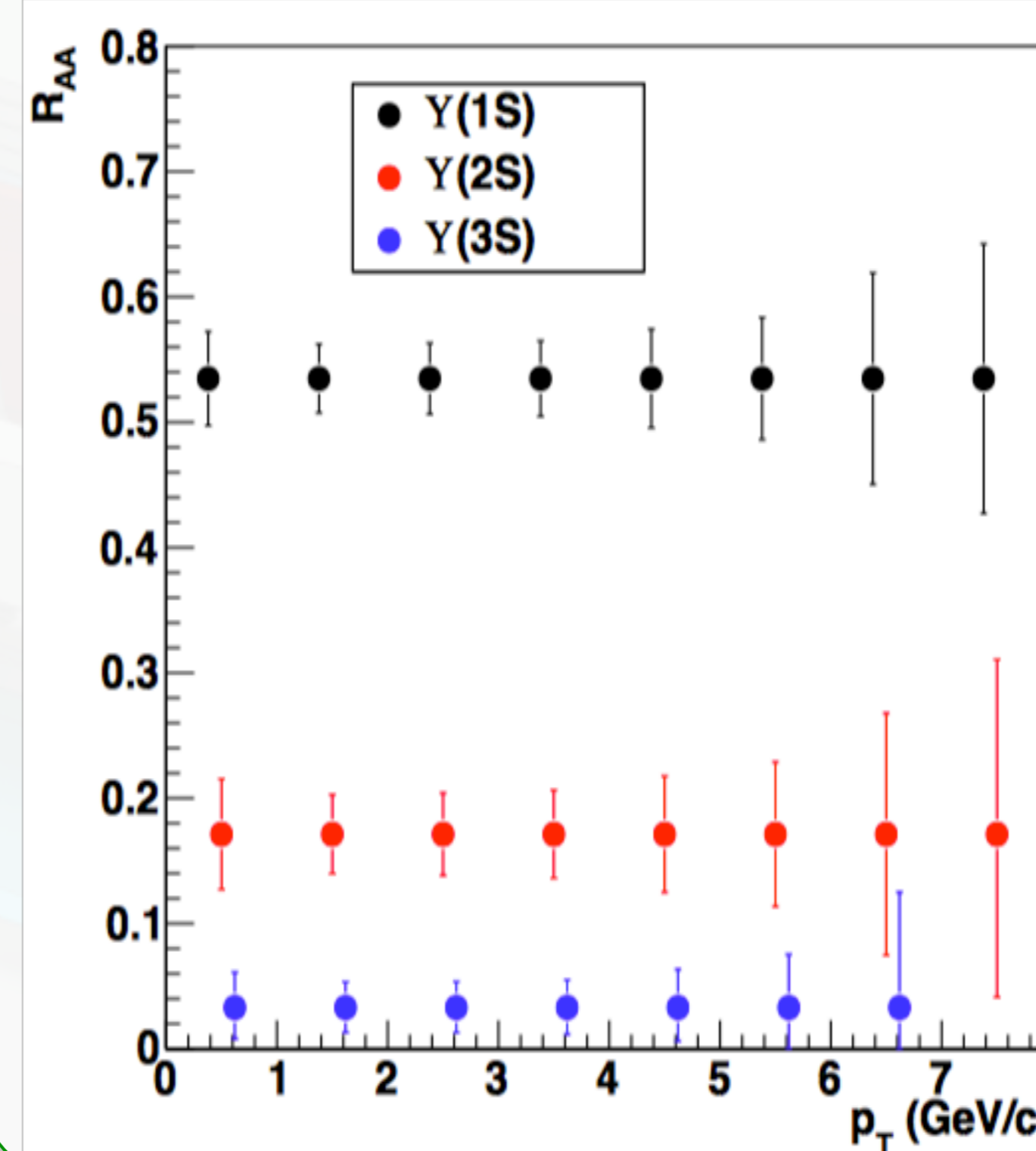
Simulated Performance

The configuration of the Intermediate silicon strip tracker is still being finalized, and therefore we cannot present here detailed simulations of the performance of the currently planned tracker. The simulations presented here are from an earlier tracking configuration which meets the specification of less than 100 MeV mass resolution for the Upsilon.



Left: Reconstructed mass of the three states $Y(1s)$, $Y(2s)$ and $Y(3s)$, assuming no suppression relative to p-p collisions. This is the same plot as shown in the Particle Identification/Background section, but has the combinatorial background (the blue curve), subtracted using event mixing. Upsilon states and the correlated background are fitted using a crystal ball function for the Upsilon states and an exponential function for the background. The crystal ball function corrects for the Bremsstrahlung (radiative) tail effects at low energies due to losses suffered within the tracker.

Right: The estimated statistical accuracy of the nuclear modification factor (R_{AA}) as a function of the number of participants (N_{part}) for the three Upsilon states, for 0-10% centrality and 100 billion Au+Au events. Here we assume the suppression follows the predicted theoretical curves given by Strickland & Bazow [2] and the signal to background ratios are adjusted accordingly.



Left: A plot of the estimated statistical precision of R_{AA} as a function of the transverse momentum (p_T) for the three Upsilon states, for 0-10% centrality and 100 billion events in Au+Au collisions. Again, the suppression assumed for all three states is taken from a theoretical calculation by Strickland & Barzow [2]. The signal to background ratio here is assumed to be independent of p_T .

References

- [1] A, Adare et al. (January 25, 2015). "An Upgrade Proposal from the PHENIX Collaboration". Retrieved from <https://arxiv.org/pdf/1501.06197v1.pdf>
- [2] Strickland, Michael & Bazow, Dennis. "Thermal Bottomium Suppression at RHIC and LHC". Nuclear Physics A 879, 25-58 (2012).